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Mössbauer Forward Scattering in the Regime of RF Hyperfine Field Reversals ($FeBO_3$): Temperature Dependence of the Spectra

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Abstract—A model of frequency and time-domain Mössbauer forward scattering (FS) spectra on a magnetic target in the regime of RF hyperfine field reversals is proposed. The model allows us to describe the temperature dependence of RF effects in the FS frequency spectra of $FeBO_3$ measured at temperatures below the Néel point (~348 K). In the proposed model, temporal (with internal mark) Mössbauer FS spectra on a magnetic target are calculated to study the dependence of the structure of these spectra on the target's optical thickness, the degree of phase correlation of the RF hyperfine field reversals, and the value of the phase of the RF field used as an external parameter.

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INTRODUCTION

Mössbauer forward scattering (FS) using natural sources was developed in [1–3]. This measuring scheme considerably expanded the possibilities of obtaining additional information in the regime of the ultrasound (US) excitation of the target (absorber). Frequency FS spectra in this case have satellite structure, but their satelite formation mechanism differs from that of US Mössbauer absorption spectra [4]. Satellites in FS spectra are formed only for thick samples, and only in the regime of in-phase oscillations of the target's nuclei. Under these conditions, the mechanism of the coherent enhancement of the forward Raman scattering of gamma-photons takes place [3]. The model of Mössbauer FS [3] led to modifications of the acoustic modulation model of absorption spectra for thick targets [5]. New possibilities of the FS geometry were revealed in Mössbauer measurements of time-domain spectra using the delayed coincidence (DC) method [6]. The structure of time-domain FS spectra in this case also is a consequence of the excitation of in-phase oscillations of nuclei in thick targets [7].

The Mössbauer FS technique was also used in [8] in the regime of radio frequency (RF) reversals of the magnetization of iron borate ($FeBO_3$), an antiferromagnet having the properties of weak ferromagnet with strongly expressed anisotropy (~60000 Oe) of the easy-plane type. In addition, $FeBO_3$ has record weak anisotropy (~1 Oe) in the easy magnetization plane and is a unique object of Mössbauer studies. It has been studied quite well with respect to its magnetodynamic and magnetoelastic properties in the RF range in particular [9]. Its FS spectra have been measured at a sample temperature of 343 K, near the Néel temperature, and were satisfactorily described using the mechanism of RF reversals of hyperfine fields on nuclei [8]. In this work, we present results of the additional measurements of the frequency spectra of FS on an $FeBO_3$ sample below the Néel temperature, the temperature dependences of which are described within the modified model. We also present a model of $FeBO_3$ time-domain FS spectra for recording with the DC scheme. The structure of these time-domain spectra depends on the phase correlation degree between the RF hyperfine field reversals on nuclei, according to the similar effects in an acoustic field [6].

MODEL OF THE RF REVERSALS WITH FLUCTUATING PHASES

As in [8], we shall analyze the consequences of RF reversals of a hyperfine field direction on Mössbauer nuclei. In contrast to [8], we now consider possible violations of the homogeneity (in space) and periodicity (in time) of the stepwise field changes on nuclei (see below). This yields a generalization of the model [8] that expands the region of adequate control (fitting) of the experimental results. With an experiment on $FeBO_3$, we are talking about establishing the mechanism of the observed temperature dependence of the FS spectra near a phase transition.

Our analysis is based on the equation for the slowly changing amplitude of a gamma wave $E(y,t) = E_\omega(y,t)\exp(-i\omega t)$, propagating through the resonance absorber [3, 8]:

$$\frac{\partial E_\omega(y,t)}{\partial y} = -\frac{2\pi}{c} J_\omega(y,t). \quad (1)$$